LHC IR Upgrade

A Dipole First Layout Option

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Scenarios for the LHC Luminosity Upgrade
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Introduction

A dipole first upgrade scenario has been developed and the optics configurations have been explored.

In detail for both beams:

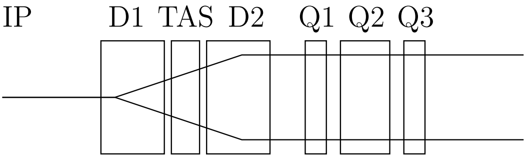
- specification of the magnets strengths and apertures;
- collision, injection and transition optics;
- crossing angle and parallel separation schemes;
- linear chromaticity correction.

Motivations

The motivations for the studies are:

- test the feasibility of the layout main hypothesis;
- test the compatibility of the not upgradable LHC ring with the new elements;
- set a reference for comparison with other layouts;

Requirements

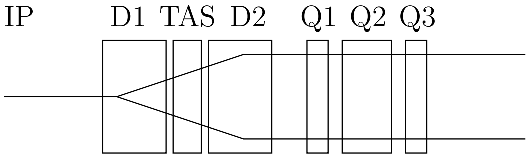


The new layout has been designed for:

- maintain all the LHC parameters
- maintain all the elements but the triplets and the separation recombination dipoles
- achieving $\beta* = 0.25$m;
- aperture, peak field for the new magnets compatible with Nb3Sn (see [1]);
- 10σ separation of the two beams.

[1] "Performance Limits and IR Design of a Possible LHC Luminosity Upgrade Based on Nb-Ti SC Magnet Technology", F. Ruggiero, O.S. Brüning, R. Ostojic, L. Rossi, W. Scandale, T.M. Taylor, A. Devred

New Elements Specifications

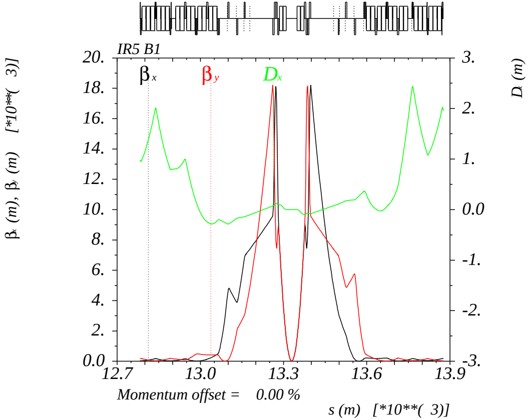


- Triplet Quadrupole: 2-in-1, 194mm separation channel.
- D2 Dipole: 2-in-1, 100mm separation channel.
- D1 Dipole: Common bore, 100mm aperture.
- TAS 1.800m long.

Magnet	d from IP	length	field	aperture
D1	19.450m	11.400m	15.1T	100mm
D2	32.670m	11.400m	15.1T	80mm
Q1	46.050m	4.550m	231T/m	80mm
Q2a	51.870m	4.500m	257T/m	80mm
Q2b	57.690m	4.500m	257T/m	80mm
Q3	57.690m	5.000m	280T/m	80mm

Collision Optics

- Maximum $\beta = 18\text{km}$
- Q4-Q7 non zero dispersion
- no left right symmetry
- no b1 b2 symmetry
- Q4,Q5 high β values
- tunability:
  $\frac{\delta \mu_x}{2\pi} = 0.016,$
  $\frac{\delta \mu_y}{2\pi} = 0.10$



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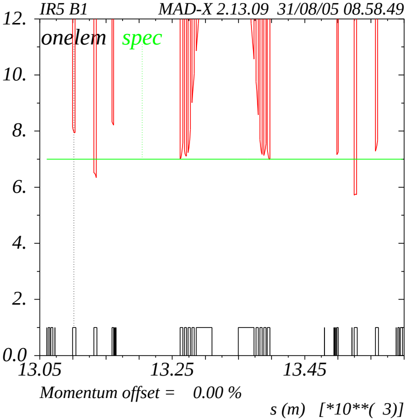

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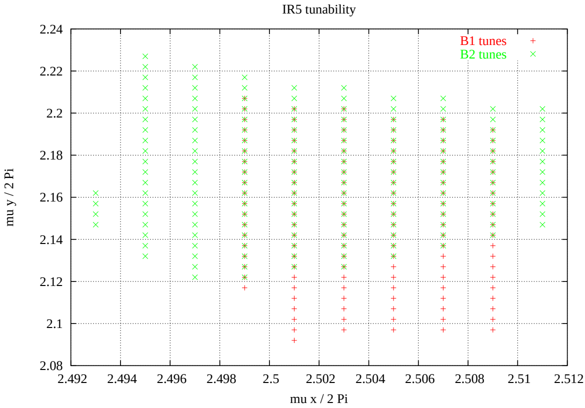


Transition to Injection Optics

The existence of a continuous path of magnet strengths to the injection is not obvious because:

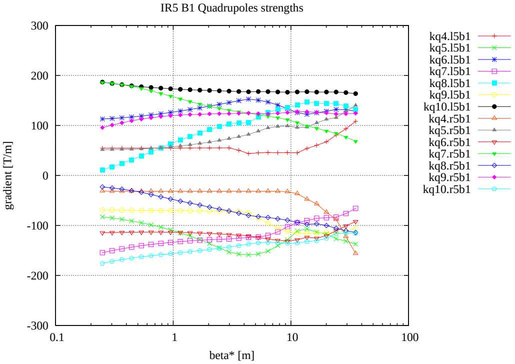
- the strengths of the quadrupoles are close to the limits;
- the beta functions are high;
- the dispersion in the matching section cuts degrees of freedom.

For this particular layout a solution has been found even if new tools needed to be developed.
The other upgrades options are less challenging for this aspect, it may be not an issue.

Transition to Injection Optics

Matching quadrupoles transition:

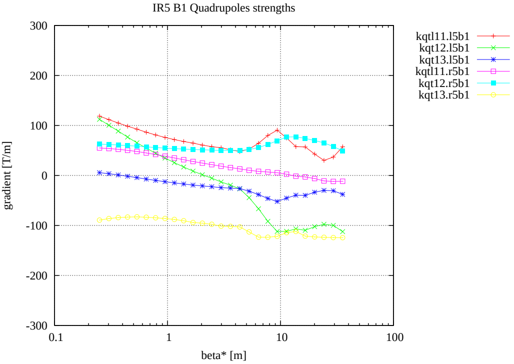
- the path is smooth
- there are few slope changes



Transition to Injection Optics

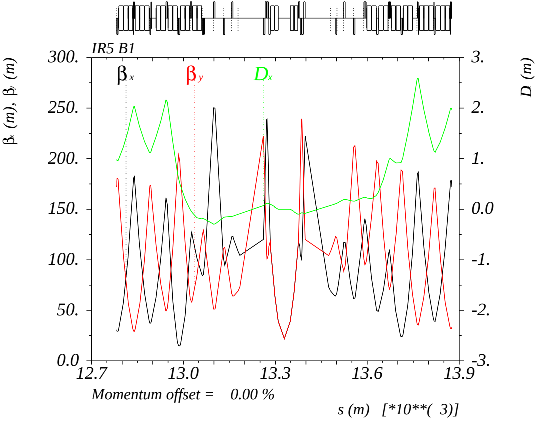
Trim quadrupoles transition:

- the path is smooth
- there are few slope changes
- there are polarity changes for the trim quadrupoles



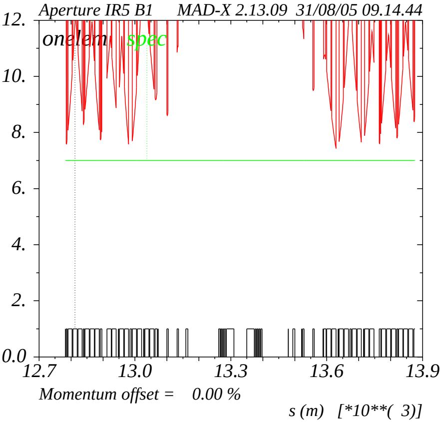
Injection Optics

- no particular issues



Injection Optics

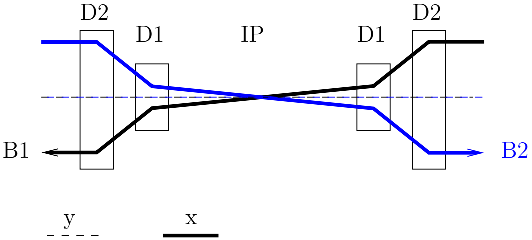
- no particular issues



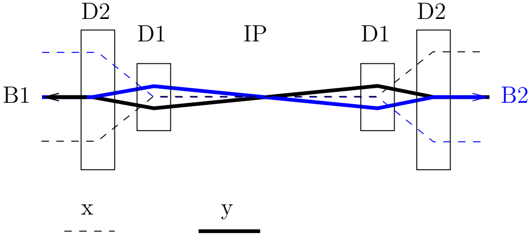
Crossing angle schemes

Crossing angle is achieved:

- for the horizontal plane by powering differently D1 and D2



- for the vertical plane by tilting D1 and D2 resulting in a vertical deflection



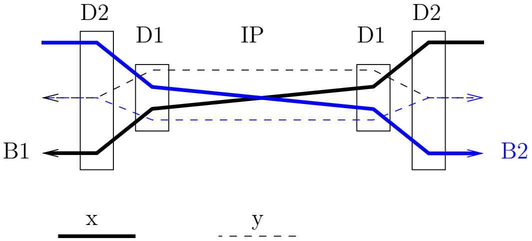
Crossing angle schemes

Separation is achieved:

- or using the orbit correctors
- or dividing D1 and D2 in two part and powering them differently

Example for the last option:

- Horizontal crossing angle, vertical separation



Separation bump schemes

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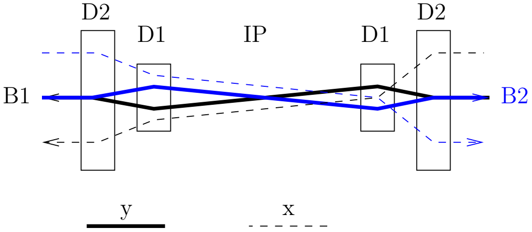
- or dividing D1 and D2 in two part and powering them differently

Example for the last option:

- Vertical crossing angle, horizontal separation



Crossing angle estimation

The crossing angle needed is based on the approximation:

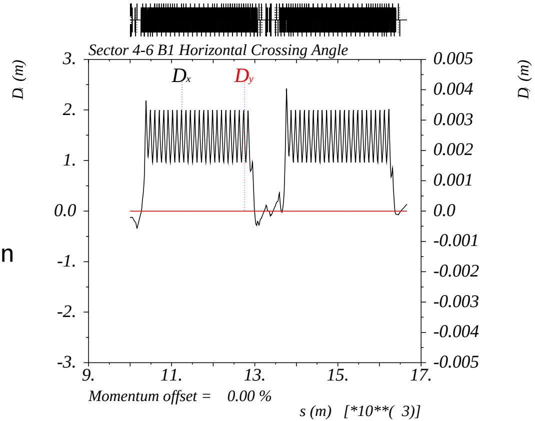
$$\frac{d}{\sigma} = \phi\sqrt{\frac{\beta^*}{\varepsilon}}$$

Data	Unit	LHC	Upg.
Energy	[GeV]	7000	7000
Relativistic gamma		7461	7461
Normalized emmittance	[μm rad]	3.750	3.750
Emmittance (ε)	[nm rad]	0.503	0.503
RMS beam size at IP	[μm]	16.63	11.21
Half crossing angle (ϕ)	[μrad]	142.5	211.4
Half separation (d)	[σ]	4.714	4.714

Crossing Angle Induced Dispersion

Dispersion when horizontal crossing angle is on:

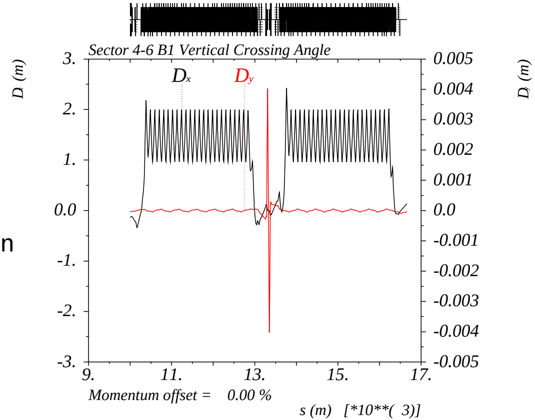
- no beating
- no needs of correction



Crossing Angle Induced Dispersion

Dispersion when vertical crossing angle is on:

- negligible beating
- no needs of correction



Chromaticity

The chromaticity is enhanced by high β values.
In LHC there are two families of available correctors, MSS focusing and defocusing and MCS

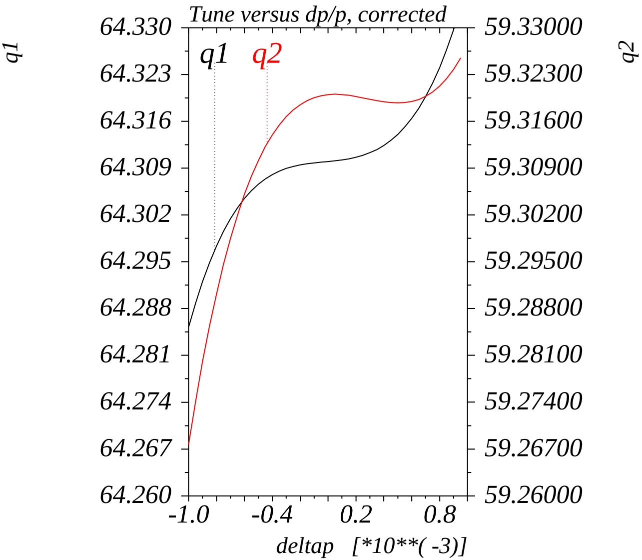
Family	Max Field at 17mm	Max k_2
MSS	1.280T	$0.379 m^{-2}$
MCS	0.471T	$0.139 m^{-2}$

The linear chromaticity correction can be achieved using:

MSS F	MSS D	MCS
54.1%	92.7%	0%
71.4%	70.0%	70.0%

The non linear terms and the beta-beta are not corrected and maybe there is not enough budget available.

Tune versus dp/p
corrected by the arc sextupoles



Conclusion (1)

- A dipole first scenario with the relevant optics configuration has been developed
- The required aperture is compatible with the elements specifications
- Probably Q5 should be replaced with 1.9K MQY
- A transition between injection and collision exist (not obvious due the dispersion in the triplets), but it has some slope inversion
- The linear chromaticity can be corrected with the sextupoles in the arcs, but not the non linear terms

Conclusion (2)

New advantages with respect quadrupole first

- Crossing schemes completely managed by D1 D2
- Horizontal dispersion is not to be corrected
- Vertical dispersion is negligible
- Natural magnetic tas (racetrack magnets)
- less long range beam-beam interaction due the early separation of the beam

Drawbacks

- TAN for the neutron flux has to studied
- Magnets technology pushed to the limits

On going studies

Questions:

- Can the chromaticity be corrected locally? Which is the effect on the dynamic aperture? (Studies started)
- Can the TAS and TAN be integrated efficiently and the radiation from the IP (10 times bigger) absorbed?
- Which are the effects of the 18km$\beta *$ on the tolerances for the ground motion, multipole errors, etc.